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Relationships between Urban Form and Travel Behaviour in Athens, Greece. A Comparison with Western European and North American Results

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In Athens, a series of political events during the last two centuries influenced urban planning, resulting in a unique land use and transport system. In this paper, we examine their relationships in this uncommon system and compare them with those in Western European and North American cities. Data from Metro Development Study (1996) were employed in multiple regression models for Athens, while results from similar studies in Western cities were used as the basis for comparisons. The results for Athens show that residential density is a key factor influencing mainly modal split, whereas distance from city centre and the extent of road network mainly influence trip length and energy consumption by car. An interesting threshold of 200 persons/ha is identified, in which significant changes in travel behaviour occur. In contrast, "land use mix" appeared to have no effects on travel behaviour. The international comparisons revealed differences regarding the density threshold and the role of land use mix, while results concerning residential density, distance from city centre and socio-economic characteristics are in line with those from other European and American cities. The case of Athens adds to the notion that land use policies could constitute a tool for changing travel behaviour. However, urban form parameters, and their critical thresholds, may vary from country to country, especially among cities in Europe and America, which means that no universal standards can be adopted. Finally, it could be argued that in all cases, if more compact urban structures are adopted, more sustainable travel patterns will emerge.

Keywords: Athens-Greece; uncommon land use-transport system; urban form characteristics; travel behaviour

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1. Introduction

During the 1990s, urban transport planning was characterised by a change on the strategic goals. The "new realism" (Banister, 1999) disconnects the implementation of transport projects from the demand, which keeps increasing. The theory of past decades, which stated that the expansion of road network would meet the needs for unrestricted demand, is now rejected. The current interest is focused on the demand restraint and management, and the promotion of public transportation and alternative means (walking, cycling). In the long-term, the interest focuses on the possibility of affecting travel behaviour through changes in the physical characteristics of the urban form. The discussion has already opened on a political level with regard to the implications of the compact city form on travel choices (CEC, 1990, 2004; Barbopoulos et al., 2006).

Nevertheless, many studies either offer contradictory results or are unable to account reliably for the relationship between urban form and travel behaviour (Badoe and Miller, 2000). According to Van Wee (2002), some of the main reasons are the various interpretations of the same parameters in different countries, variability in culture and outlook, particularly with regard to travel behaviour, and the indirect effects of land use and socio-economic characteristics on travel behaviour. Moreover, most research has been carried out in American cities, which is another reason why such studies should be interpreted with caution when applied to Europe. Historically, European cities have followed a different development model, particularly with regard to densities and mixture of land uses. However, even among European cities, important differences exist in urban structure and development. In Athens, a series of political situations during the last two centuries (Turkish occupation, Bavarian royalty, refugees' arrival from Western Turkey, dictatorship) has significantly influenced urban planning and development, resulting in a unique urban form and transport system. In the present study, the relationships in this uncommon system are examined in order to identify the urban form characteristics that influence travel behaviour, determine the role of the special spatial and transport features of Athens in these relationships, and finally, establish the differences with results from similar studies in other Western cities.

First, Athens' urban form and transport characteristics are analysed, aiming to elucidate the existing differences compared to other Western cities (section 2). The data and research methodology are presented in section 3, while in section 4, the results are discussed and correlated with the city's urban form, socio-economic structure, and transportation system. In section 5, a comparison is drawn between our results and those of similar studies carried out in other European and American cities. Finally, section 6 presents the conclusions.

2. An analysis of Athens' land use-transport system

2.1 Historical dynamics

Following a long period of occupation by the Ottoman Empire (1453-1821), Athens was proclaimed the capital of the new Greek state in 1834. However, the city started playing a leading role in the development of the country no sooner than the first decade of the 20th century (Burgel, 1976). Its population grew abruptly in the following years due to major migration waves, the first one in 1922, of Greeks living along Turkey's west coast and a second internal migration wave of people arriving from rural areas immediately following World War II (Figure 1). Other factors that influenced the city's development were the Civil War (1946-1949) and a Dictatorship (1967-1974).

These historical landmarks created an unstable political, social, and economic environment in Greece, and especially in Athens, which influenced the spatial development. Urban and transport planning were almost absent and private interests were free to speculate. Housing development was funded by the capital of small land owners and whole suburbs were authorised after they were constructed (Maloutas, 1990; Phillipidis, 1990). It was only in 1985 when a political framework of urban planning was institutionalised for the first time (OJHR, 1985) but its basic principles have not been applied yet, while there is no such a framework for transportation planning.

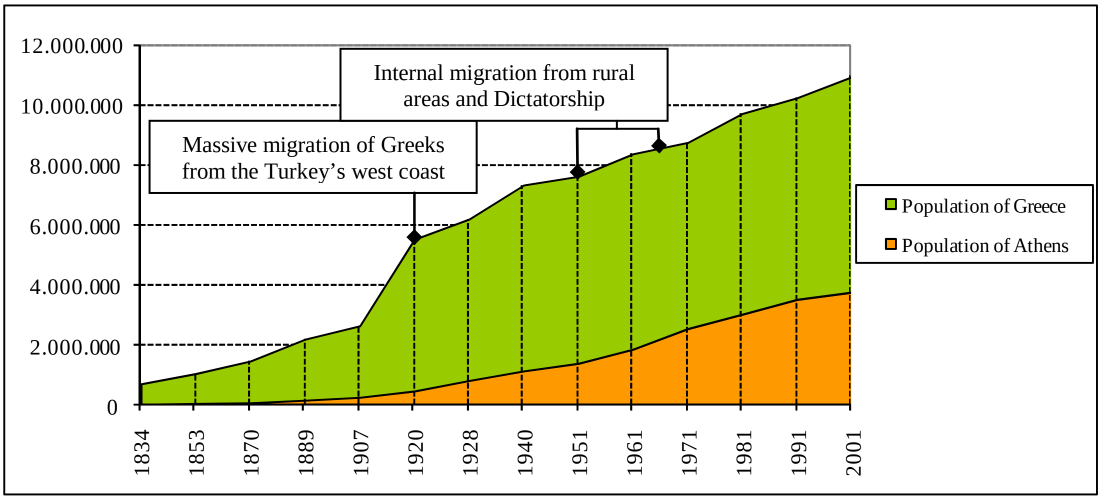

Figure 1. Population growth and historical landmarks from 1834 till 2001 in Athens
Source: Leontidou, 2001, p. 301

2.2 *Differences compared to the North American and Western European city*

Although Athens is a metropolis of 4 million citizens, its form is typically monocentric. Approximately 25% of the population lives, and 30% works, in the centre. No important sub-centres have developed until now, whereas working places (mainly of the tertiary sector) have been concentrated across radial arteries leading to the city centre. This monocentric form is accompanied by high residential densities, particularly in central areas (Table 1). In Athens, a high percentage of the population still lives in the centre, which explains the low rate of suburbanisation compared with other European and, certainly, North American cities. Low suburbanisation could also be attributed to the topography of the city (Athens lies in a basin of 1270 km^2, where 95% of the population lives, surrounded by sea and mountains), the limited development of the road and regional train network, and the fact that car ownership increased considerably only in the 1980s, approximately 20 years after the rest of Western Europe and 40 years after North America. The compact monocentric form of Athens is also strongly characterised by the mixture of land uses. In many cases, functional problems arise when various, incompatible land uses co-exist in close proximity. Lack of planning and a high percentage of small-scale businesses are the main sources of irrational allocation of land uses. It could be argued that Athens represents an explicit example of "non-planning", the opposite of zoning, applied mainly in North American, and secondarily, in Western European cities during the period of modernism. In the latter, land use mix can mainly be identified in the centre due to historical reasons.

Urban form abnormalities have also influenced the development of the transport system. Nowadays, traffic congestion is severe and traffic speed is quite slow (Table 1). The road network's design causes further traffic problems, following a mixed shape of small rectangular blocks, narrow streets, and radial avenues leading to the centre. This model varies from suburb to suburb, where economic interests and planning failures shaped unique road network forms and urban structures (Figure 2). The irregularities in the road network cause major problems for the operation of a public transportation system that is mainly based on buses. In 1996 (base-year of the research), buses did not operate in dedicated lanes, their commercial speed was low (16.8 km/h) and they were strongly influenced by traffic conditions. It should be noted that historically, the public transport network in Athens has followed urban development, as it was planned to serve mainly the high-density areas following their establishment (Vlastos, 2006). Even in the case of the sole metro line, no major developmental impacts were observed (Tzouvadakis, 1992). It should, however, be mentioned that in the last decade (1997-2007), two new metro lines, two lines of suburban railway (120 km) and one additional tram line (26 km) were constructed, providing a substantial improvement in public transport services, which nonetheless, still lag behind Western European cities.

Table 1. Residential densities and transportation system characteristics in Athens and other Western cities

(1990)	Gross residential density (persons/ha)		Traffic characteristics		Public transport characteristics	
	Metropolitan area	Centre	Road supply (m/person)	Average speed of traffic (km/h)	Transit service level (vehicle km of service/person)	Average speed of buses
Athens (1996)	73	242	0.7	19.8	24.7	16.8
Frankfurt	47	66	2.0	45.0	47.9	19.6
Stockholm	53	101	2.2	43.0	133.2	27.2
Copenhagen	28	75	4.6	50.0	121.3	24.2
Paris	46	180	0.9	25.7	71.0	19.3
Amsterdam	50	93	2.6	35.0	60.3	16.3
London	42	63	2.0	30.2	138.4	19.0
Houston	10	18	11.7	61.2	16.7	23.6
Phoenix	11	17	9.6	51.5	9.9	24.5
Detroit	13	17	6.0	56.3	14.0	22.5
Los Angeles	24	28	3.8	45.0	19.8	19.9
Washington	14	27	5.2	42.4	37.3	19.3

Source: Newman and Kenworthy, 1999, p. 82-83; AM-DPGS, 2000, p. II-68

Figure 2. Two examples of irregular road networks in Athens

3. Research Data and Methodology

3.1 Data

The metropolitan area of Athens consists of 82 municipalities, with a total population of 3,833,400 persons (1996). The spatial unit for the present analysis is the municipality, with an average population and size of 45,000 persons and 15 km^2, respectively. Data were derived from surveys carried out by the Metro Development Study (MDS), in 1996 (AM-DPGS, 1997, 2000). The land use surveys covered 74,500 hectares (66,600 blocks), while the travel and socio-economic characteristics of households were collected through a total of 29,358 interviews (general sampling: 2% of the population). All household members, over 10 years of age, were interviewed in person. Each questionnaire was divided into three parts. The first one regarded household characteristics (size, car ownership, income, type of housing), the second asked about personal characteristics (gender, age, education, job details, driving license), and the third segment contained a 24-hour travel diary for the day preceding the interview. Walking trips covering distances greater than 500 m were not recorded. Each household member older than 18 years of age was asked to answer the first two parts, while each household member over the age of 10 years provided his/her travel characteristics separately.

3.2 Methodology

We decided to focus on those urban form characteristics that provide a precise picture of Athens' compact monocentric structure and its differences with other Western cities. Hence, we used residential density, two indicators for the spatial allocation of land uses (jobs-employment and land use balance), one indicator for suburbanisation level (distance from centre), and one indicator for the development of the road network (road space per person) (Table 2). The 'Jobs-employment balance' (JEB) was defined as the ratio of jobs in a municipality to the number of the municipal inhabitants employed within the overall study area, while 'Land use balance' was defined in terms of the entropy index (Cervero, 1988; Frank and Pivo, 1994; Messenger and Ewing, 1996; Kockelman, 1997). Finally, 'Distance from centre' was defined as the Euclidean distance between each of the 82 municipalities and the municipality of Athens, which corresponds to the historical centre accounting for 921,000 inhabitants and the majority of jobs and central activities.

$$JEB = \frac{Number\ of\ jobs}{Number\ of\ employees} \tag{1}$$

$$Entropy = \sum_i \frac{P_i \ln(P_i)}{\ln(I)} \tag{2}$$

P_i: The percentage of land use i, for the whole area.
I: The number of land use categories included in the equation.

The spatio-social differences in Athens required the addition of travellers' socio-economic characteristics, when analysing the relationships between urban form and travel choices, in order to gain a better understanding of the network relations. Thus, we included in the study, car ownership, household income and household size (Table 2).

We investigated the influence of the above urban form and socio-economic characteristics on trips per person per day, by car and public transport, walking trips, mean length of trip by car, and per capita energy consumption by car. The mean length of trip (MLT) by car was calculated by using the O-D matrix at the municipal level as follows:

$$MLT_i = \frac{\sum_i t_{ij} d_{ij}}{\sum_i t_{ij}} \quad (3)$$

t_{ij}: Number of trips by car from municipality i to municipality j.
d_{ij}: The Euclidean distance between municipalities i and j.

The per capita energy consumption by car was calculated on the basis of mean fuel consumption per kilometre, with the help of the CORINAIR-COPERT III programme equations[4] (Ntziachristos and Samaras, 2000) and data on fleet composition (NSSG, 1994).

Table 2. Descriptive statistics of urban form and socio-economic parameters

Parameter	Unit	Mean	S.D.	Min.	Max.
Urban Form Parameters					
Net residential density	persons per hectare	218	197	6	903
Jobs-employment balance	jobs per employee	1.080	1.312	0.102	7.906
Land use balance	net number	0.510	0.169	0.072	0.841
Distance from centre	m	10,752	5,817	3,508	29,879
Road space per person	m^2 per person	116.0	229.6	8.0	1,701.5
Socio-economic parameters					
Household income	€	889	390	402	2,638
Car ownership	number of cars per thousand inhabitants	279	76	138	471
Household size	persons per household	3.13	0.32	2.50	4.13

Our methodology was structured on two levels. On the first level, the aim was to investigate whether Athens' urban form characteristics influence travel behaviour and which one(s) explain the variability in each of the five travel characteristics chosen for this study. Five multiple regressions were performed, with travel characteristics serving as the dependent variables. In each multiple regression, the final model was approached in successive steps, which sequentially calculating the level of significance for all parameters and the total explanatory power of the model. On the second level, the aim was to compare the degree of influence exercised by urban form and socio-economic characteristics on travel behaviour and to identify any mutual influences. Stead's (2001) research methodology was adopted: firstly, the R^2-value was determined separately for urban form and socio-economic characteristics. Next, a third multiple regression was applied, in which all the parameters were included as explanatory variables. This third calculation allowed for comparing the degree of influence exercised by every group of parameters on travel characteristics and drawing conclusions about the validity of the first level results. It should be noted that no causal relations can be identified using this methodology.

4. Results

4.1 First level of analysis

The results of the first level of the analysis clearly demonstrate that residential density is one of the most important parameters influencing travel choices in Athens (Table 3).[5] It is positively correlated with the use of public transportation and walking, and negatively with car trips, mean trip length, and energy consumption by car. These relationships are better described by a

[4] The variables in the CORINAIR-COPERT III equations are the year of manufacture, the engine's power, and the average speed in urban areas.
[5] For a more detailed analysis of the regression steps, see Milakis (2006).

logarithmic curve, in which a threshold of 200 persons per hectare can be identified (Figure 2). Below this value, increases in the residential density lead to a significant increase in the number of public transportation and walking trips, and a decline in the number of car trips, mean trip length, and energy consumption by car. Above this level, however, the modal shift lessens considerably, as the relationship between density and travel characteristics becomes nearly linear (Table 4). The threshold of 200 persons per hectare defines two areas in Athens with different characteristics, thus justifying the above findings (Figure 3). The first area is the compact region with high densities (> 200 persons/ha), central activities, good public transportation services, and limited parking availability, while the second one (< 200 persons/ha) can be characterised as the suburban region with lower densities, no central activities, and poor public transport services. As no important secondary centres exist in the suburban region, people are still obliged to commute to the central compact area by using, in most cases, their private car, as there are no alternatives. Consequently, the distance from the centre constitutes a crucial parameter influencing their trip's length by car. According to our findings, an increased distance from city centre by 1,000 meters is capable of increasing a trip's length by 210 meters. This length is also affected by the road network's level of development, which is more extensive and presents better geometrical characteristics in suburban than central regions. The results show that an increase of 10 m^2 in road space per person may lead to an increase in trip length by 46 meters. This observation is consistent with another study's findings, which discovered a 'driving pleasure' factor in the undertaking of trips by car, mainly for leisure or even for work (Mokhtarian and Salomon, 1999; 2001). Finally, based on our results, the balance between different land uses does not seem to influence travel choices in Athens. Land use mix is an inherent feature of both central and suburban areas, and a relic of Athens' history of development, as no zoning principles were ever applied.

Table 3. The most crucial characteristics of urban form affecting travel behaviour in Athens

Parameters entered in the base model	Final models (1st level of analysis) (n = 82)				
	Public transport	**Car**	**Walking**	**Mean trip length by car**	**Energy consumption by car**
	Constant: 0.125 (2.011/0.048)[a]	Constant: 1.828 (14.579/0.000)	Constant: 0.050 (-1.300/0.197)	Constant: 6,282.539 (4.449/0.000)	Constant: 41.843 (4.388/0.000)
Net residential density (Logarithmic transformation)	0.050 (5.456/0.000)	-0.190 (-8.127/0.000)	0.025 (3.138/0.002)	-428.736 (-1.929/0.058)	-5.305 (-3.535/0.001)
Jobs-employment balance	0.018 (2.953/0.004)	-0.089 (-3.991/0.000)	--	184.386 (1.699/0.094)	-2.537 (-3.463/0.001)
Land use balance	--	--	0.140 (2.397/0.019)	--	--
Distance from centre	-6.0E-06 (-3.032/0.003)	--	--	0.210 (5.904/0.000)	4.0E-04 (1.651/0.103)
Road space per person	--	--	--	4.576 (2.578/0.012)	0.041 (3.393/0.001)
Adj. R^2	0.625	0.451	0.230	0.799	0.731
F-value	45.979[b]	34.204[b]	13.129[b]	71.470[b]	49.247[b]
Df (k, n-k-1)	3, 78	2, 79	2, 79	4, 77	4, 77

[a] (t-value / significance)
[b] statistical significance of 1%

Table 4. The effects of density increases on travel characteristics in two examples

	Residential density increase from 10 to 30 persons/hectare	**Residential density increase from 210 to 230 persons/hectare**
Trips/person by car	-18.6%	-1.6%
Trips/person by public transport	+6.9 %	+0.6%
Trips/person on foot	+24.1%	+1.9%
Mean trip length by car	-30.7%	-2.5%
Energy consumption by car	-37.2%	-3.1%

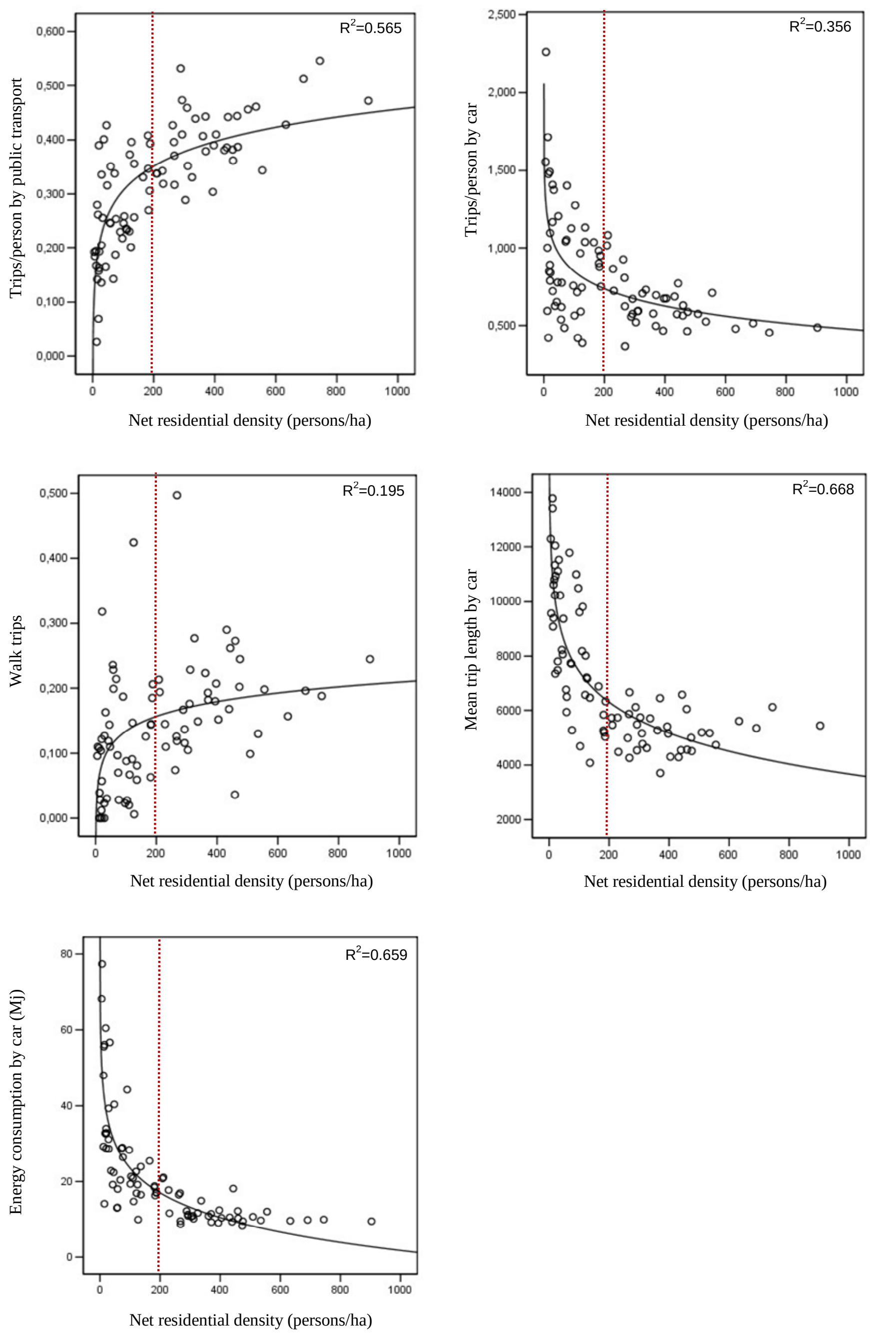

Figure 2. Graphical representation of the relationship between density and travel characteristics

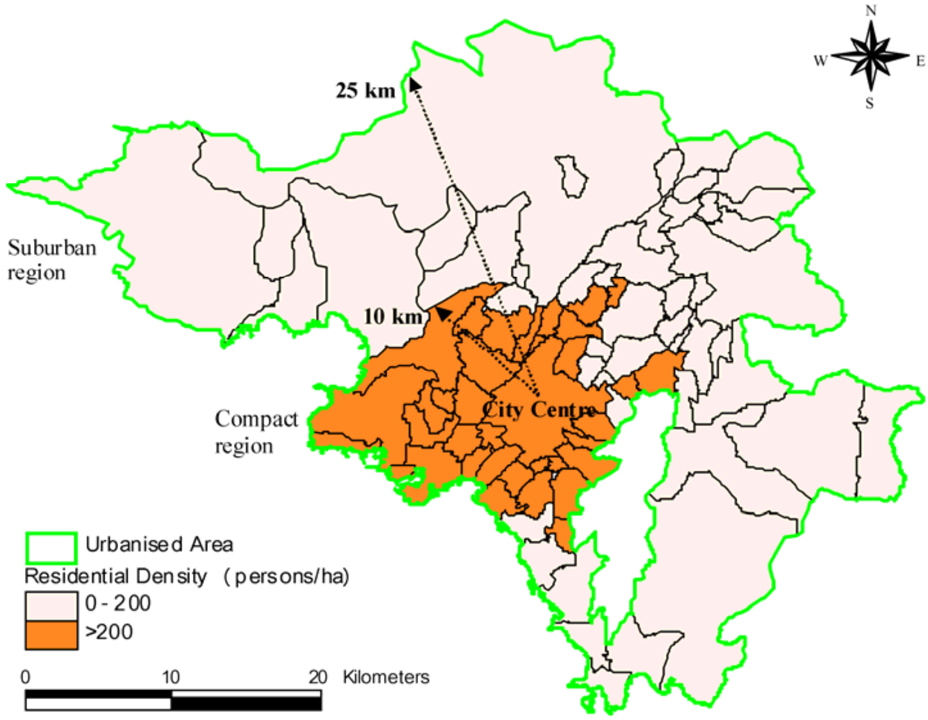

Figure 3. The compact and suburban regions in Athens, defined by a density threshold of 200 persons/ha.

4.2 *Second level of analysis*

The second level of analysis allowed us to validate the previous first level's results, by comparing the degree of influence of urban form (UF) and socio-economic (S-E) characteristics (income, vehicle ownership, household size) on travel behaviour. The results show that UF seems to explain most of the variability in public transportation trips, mean trip length, and energy consumption by car, whilst S-E characteristics appear to have a greater effect on car trips. Walking trips are not influenced by any of the above mentioned factors (Table 5).

Table 5. Results of multiple regression analyses performed, comparing the influence of UF and S-E on five travel characteristics

n = 82	R^2-values				
	Public transport	**Car**	**Walk**	**Mean trip length by car**	**Energy consumption by car**
All UF	0.639	0.464	0.249	0.810	0.746
All S-E	0.374	0.756	0.173	0.191	0.572
All UF and S-E together	0.664	0.762	0.302	0.827	0.864
Range of influence of UF[a]	0.290 – 0.639	0.006 – 0.464	0.129 – 0.249	0.636 – 0.810	0.292 – 0.746
Range of influence of S-E[b]	0.025 – 0.374	0.298 – 0.756	0.053 – 0.173	0.017 – 0.191	0.118 – 0.572
UF model Df (k, n-k-1) = 5, 76					
S-E model Df (k, n-k-1) = 3, 78					
UF & S-E model Df (k, n-k-1) = 8, 73					

[a] The R^2-value for all UF gives the maximum value for the range of influence of UF. The minimum value occurs when the R^2-value for all S-E is subtracted from the R^2-value for all the UF and S-E together.
[b] The R^2-value for all the S-E gives the maximum value for the range of influence of S-E. The minimum value occurs when the R^2-value for all the UF is subtracted from the R^2-value for all the UF and S-E together.

More specifically, the R^2-value of UF with regard to public transportation trips varies between 29.0% and 63.9%, whilst, by contrast, the R^2-value of S-E varies between 2.5% and 37.4%, nearly half of the UF values. The same holds true for mean trip length by car, which is influenced almost exclusively by the UF. The range of influence varies between 63.6% and 81%, while that exercised by S-E varies from 1.7% to 19.1%, thus forming a ratio of 5:1 between them. Concerning the energy consumption by car, the results indicated that UF and S-E exercised a more balanced influence. This is a logical result, since energy consumption depends, as much upon the number of car trips, as it does on their length. Given the fact that car trips are influenced more by S-E (R^2-value varies between 29.8% and 75.6%, being more than double that of UF), whilst the length of the trip is affected more by UF, it is to be expected that both categories influence energy consumption. Of particular importance, the explanatory power of UF and S-E was found to be very low for walk trips. It would seem, then, that one or more explanatory variables need to be sought, in relation to the quality of the pedestrian environment (e.g. width of pavement, pedestrianisations, open spaces, low levels of noise and pollution, aesthetics of urban environment, and so on). This conclusion rests on the fact that only walk trips greater than 500 m in length were recorded by the Metro Development Study. These trips are undertaken only after serious consideration of the above parameters.

5. Comparisons with results from Western European and North American studies

5.1 Residential density

The results derived for Athens are similar to those from other studies conducted in Western cities, indicating that residential density influences modal split, trip length, and energy consumption by car. For example, Newman and Kennworthy (1989; 1999) argue in a study of 32 cities worldwide, that increasing density will lead to a rise in trips undertaken by public transport and a decrease in energy consumption by private transportation. In the studies by ECOTEC (1993) and Stead (2001) in Great Britain, it was concluded that an increased density was correlated with the reduction of mileage and an increase in the number of public transport trips. Further studies from North American cities also presented similar results by showing that the increase of density can cause modal shift from the private car to public transport and relevant changes in mileage (Dunphy and Fisher, 1996). In the case of Washington D.C., Frank and Pivo (1994) argue that the increase in density can cause a reduction in single occupancy vehicle (SOV) trips and increase the number of walking and bus trips.

Although the conclusions are similar, our results from Athens differ substantially in the density threshold (200 persons/ha), which correlates with important changes in travel behaviour (Table 6). It is obvious that in Athens, density is already relatively higher than in other cities, influencing the development of the transport system and, consequently, travel choices. Given that the public transport network is mainly developed in high density areas, with the simultaneous existence of a poor road network in these areas, a greater usage of public transportation means and walking is expected. On the contrary, in Western European cities, and mainly in US cities, the public transportation system is also developed in areas having lower population densities. Consequently, the density threshold is expected to be quite lower (see also Milakis *et al.*, 2005).

Table 6. Density thresholds in different countries

Study	Area	Density threshold
Present study	Athens	200 persons/ha
Newman and Kenworthy, 1989	32 cities worldwide	30 persons/ha
Stead, 2001	Great Britain	40-50 persons/ha
Frank and Pivo, 1994	Washington D.C.	32 persons/ha[a]
Dunphy and Fisher, 1996	USA (NPTS 1990)	24 persons/ha[a]

[a] These values represent gross residential density. The corresponding values for net residential density are expected to be slightly higher.

5.2 Land use mix

Land use mix has minimal influence on travel behaviour in Athens. On the contrary, many studies concerning mainly North American cities have argued for the opposite. For example, Cervero (1988), in his research of 57 suburban employment centres, found that single use environments lead to greater use of private vehicles. In particular, a 20% increase in office space was found to correlate with an increase of SOV trips of 2.4% and a 1.1% reduction in trips using collective transport modes. A more recent study (Cervero and Kockelman, 1997) involving 50 neighbourhoods in San Francisco found similar results, as well as a study by Kockelman (1997), also conducted in San Francisco. In Washington D.C., the relationship between land use mix and travel choices was confirmed by Frank and Pivo (1994). They argue that land use variety is correlated with a reduction in SOV trips and an increase in public transportation use and walking, especially for work trips. In contrast to the above studies, Stead (2001), in his research in Great Britain, did not find a correlation between land use mix and trip length per capita, a result concordant with the present study. As mentioned in Section 2, European cities differ significantly from American cities, particularly with regard to land use mixtures. This may explain why land use mix does not appear to have a significant effect on travel behaviour in Europe, and especially in Athens. In American cities, where single use environments prevail, it is quite reasonable for the studies to identify parameters related to land use variety as important, in order to change travel choices.

5.3 Distance from city centre

Concerning the distance from the city centre, the results of the present study are in agreement with those from Western European and North American studies. In Athens, this parameter was found to significantly influence trip length and energy consumption by car. Naess *et al.* (1995) have drawn the same conclusions for the city of Oslo. In their case, the increase in distance from 4 to 12 kilometres led to a 78% increase in weekly mileage. Curtis (1995), in his study of Oxford, verified this relationship but only for work-related trips. Furthermore, Miller and Ibrahim (1998) found in their research of Toronto that an increase in distance from city centre by 1 km leads to an increase in commuting mileage of 0.25 km, per employee, whereas an increase in distance by 1 kilometre from other subcenters with high employment density caused an increase of 0.38 km. Finally, the relationship between distance from the centre and energy consumption by car was verified in two separate case studies conducted in Paris and London by Mogridge (1985).

5.4 Socio-economic characteristics

The results of the present study show that the socio-economic characteristics mainly influence the number of trips by car (up to 75.6% of car trips variability), yet they do not influence trip length by car (up to 19.1% of trip length variability). As for energy consumption by car, socio-economic characteristics and UF have an almost equal influence on both, the number of trips by car and trip length. Many studies from Western European (Naess *et al.*, 1995; Dieleman *et al.*, 2002; Nunes da

Silva and de Abreu e Silva, 2003) and North American cities (Schimek, 1996; Kitamura *et al.*, 1997) have also shown that socio-economic characteristics influence car use. However, the results for trip length and energy consumption by car are quite different.

In a study of Great Britain (Stead, 2001), socio-economic characteristics were found to influence travel length, explaining up to 55% of the variability, while on the contrary, the respective percentage of urban form characteristics reached only 27%. According to Stead (2001), car ownership represents one of the most critical parameters that influence travel length. Moreover, Cervero (1996) argues that the daily commuting distance increases with an increase in income. Finally, Naess *et al.* (1995), in their study of Oslo, proved that energy consumption for transportation and the total mileage per person per week are influenced mainly by vehicle ownership. In the above studies, the parameter used was "total travel length" (or energy consumption) by motor vehicles (public transport included), not the mean trip length by private car. We assume this is the reason behind the differences in results, rather than differences in travel behaviour of various socio-economic groups living in Athens, Western European, and US cities. Indeed, in these studies, households that did not own a car were also included in the calculation of total travel length. These households tended to travel shorter distances, as they used only public transportation, a bicycle or walked in their daily travel. As Naess et al. (1995) note, *"car ownership implies increased mobility, increasing both the 'cruising range' of a household and the ability to take frequent trips."* In the Athens case study, we used mean trip length by car, which reasonably is influenced by the place of residence (especially in relation to the city centre) than the socio-economic status of the traveller.

6. Conclusions

During the last two decades, a great number of studies, particularly in Western European and North American cities, have concluded that urban form characteristics affect travel choices. In many cases, this conclusion was integrated into urban policy guidelines, especially in Europe, where increased density levels are suggested for European cities in order to promote sustainable mobility (CEC, 2004). Is it realistic to generalise these research findings and bring them into policy practice? In our study, while aiming to answer this question, we examined the relationship between urban form and travel behaviour in Athens, a city with a unique land use and transport system. Our results confirmed the presence of this relationship, but they also presented significant differences with the results of similar studies undertaken in other Western cities, indicating the difficulties in formulating general policies in this field.

Indeed, Athens represents a special study case, as a series of political events during the last two centuries influenced urban and transport planning, resulting in remarkably high densities, a monocentric form, a high mix of land uses, even extending to the city's outskirts, limited and irregular road networks, and a restricted public transportation services. In our study residential density was found to be one of the most influential parameters, affecting mainly modal split, a relationship which has been confirmed by many previous studies conducted in other Western cities. However, Athens' high residential densities seemed to influence its threshold, for which significant changes occurred in travel behaviour. In the logarithmic relationship between density and all travel characteristics, we identified a 200 persons/hectare threshold, which is much higher than respective thresholds in other Western cities. This threshold level prompted the identification of two different parts of the city, with entirely different characteristics. According to our research, densities in central areas should be preserved, or even slightly reduced in several neighbourhoods. On the contrary, in the second area, consisting of the city's suburbs, an increase in density is feasible. Density increases would be more efficient if they were implemented in areas surrounding stations of heavy public transport means, which have now been developed in Athens. If density increases are accompanied with a decentralisation of activities from the city's core to the subcentres, it should be expected that not only the number of trips by car would decrease, but also trip length. Our analysis has shown that nowadays, Athens has a monocentric form, with an increasing distance from the centre causing a rise in mean trip length by car, especially in suburban areas. It was also found that in suburban areas, citizens cover greater distances by car because of the existence of an extensive and not congested road network. The former two parameters were also found to have an impact on trip length in other Western cities. However, this does not hold true for land use mix, which does not affect travel choices in Athens. This may be attributed to the high level of land use mix that characterises the entire city, without substantial differences between the centre and its periphery. On the contrary, in other Western and especially American cities, where single use environments prevail, this factor is considered to be crucial for policies aiming to change travel behaviour.

In conclusion, our study of Athens confirmed the existence of a relationship between urban form and travel behaviour, and added to the notion that land use policies could constitute one of the tools toward sustainable mobility. However, the crucial urban form characteristics, and their critical thresholds, may vary from one country to another, in particular, among cities in Europe and the United States, which means that no universal standards can be adopted. It is therefore proposed that, in every case, one should first analyse the existing local relationships between land uses and transport in order to ensure that any policies subsequently applied would be effective. It is also assumed that a general trend towards more compact urban structures (higher densities and limited urban expansion) should be adopted in all cases to enhance sustainable travel patterns. In Athens, where only recently the metro, tram, and suburban railway networks have been developed, it is a great opportunity to implement such measures, by tailoring the city around these public transportation stations.

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